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SPACE SHUTTLE FRCI-12 TPS TILE VENTING
TEST IN THE NASA/AMES
RESEARCH CENTER 11x11-FOOT AND
9x7-FOOT WIND TUNNELS (OA307A/B)

by

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Prepared under NASA Contract Number NAS9-16283

by

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for

Systems Engineering Division
Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas

WIND TUNNEL TEST SPECIFICS:

Test Number:	ARC 11TWT 549-1	ARC 97SWT 549-1
NASA Series Number:	OA307A	OA307B
Fixture Number:	96-0	81-0
Test Start Date:	May 27, 1982	June 25, 1982
Test Completion Date:	May 27, 1982	June 25, 1982
Test Occupancy Hours:	20	24
Test Article:	FRCI-12 Tile Panel (Modified from OS57)	FRCI-12 Tile Panel (Modified from OS57)

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ABSTRACT

An experimental investigation (OA307A and OA307B) was conducted at the NASA/Ames Research Center. Test OA307A was conducted in the 11x11-foot Transonic Wind Tunnel on May 27, 1982. Test OA307B was conducted in the 9x7-foot Supersonic Wind Tunnel on June 25, 1982. Each test was completed in one day.

The purpose of these tests was to obtain venting characteristics and internal pressures of fibrous reinforced composite insulation (FRCI-12) TPS tiles when exposed to pressure gradients associated with aerodynamic shocks during Space Shuttle ascent conditions.

A single flat panel incorporating three FRCI-12 tiles was installed in each tunnel and tested in a two-dimensional flow field with an expansion/recompression shock at $M = .78$ to $.88$ in the 11x11-foot tunnel and with a compression shock at $M = 1.8$ in the 9x7-foot tunnel.

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INTRODUCTION

The purpose of tests OA307A and OA307B was to obtain venting characteristics and internal pressures of FRCI-12 TPS tiles when exposed to pressure gradients associated with aerodynamic shocks during Space Shuttle ascent conditions. Two aerodynamic shock environments were studied: an expansion/recompression shock in the 11x11-foot tunnel which simulated the upper canopy flow field and a compression shock (9x7-foot) which represented the forward canopy flow field.

A single, flat panel incorporating three FRCI-12 tiles was installed in each tunnel. In the 11x11-foot tunnel, a two-dimensional flow field was created over the test article in which an expansion/recompression shock was positioned on the test article. Mach number was varied from 0.78 to 0.88 at a constant tunnel total pressure of 22 inches of mercury and flap angle of 18 degrees. Shock pressure gradient was varied from 1.35 to 1.82 psi. Two points were taken at Mach 0.78 and 0.80 for a tunnel total pressure of 28 inches of mercury.

In the 9x7 tunnel, a compression shock was generated by a variable-angle trailing edge flap which spanned the width of the tunnel. Dynamic pressure was set at 660 PSF and 860 PSF for a constant Mach number of 1.8. The flap was varied from zero degrees to 55 degrees which varied the shock location and strength from 0 to 1.73 psi.

This report presents information on the conduct of the tests, details of the test fixtures and test article, test facility and instrumentation, and plotted data.

NOMENCLATURE

<u>Symbol</u>	<u>Definition</u>
AFRSI	Advanced Flexible Reusable Surface Insulation
ANC	American National Course
ANF	American National Fire
C_p	Pressure coefficient
$\delta_{\text{Flap}}, \delta_F$	Test fixture flap setting, degrees
FRCI	Fibrous Reinforced Composite Insulation
I.D.	Identification
IML	Inner Mold Line
INSTR.	Instrumentation
L.E.	Leading Edge
L.H.	Left Hand
M, M_∞	Freestream Mach number
OML	Outer Mold Line
ΔP	Pressure differential across shock wave
P_ℓ, P	Local static pressure, psia
P_∞	Freestream static pressure, psia
PSF, psf	Pounds per square foot
PSI, psi	Pounds per square inch
psia	Absolute pressure in psi
P_t	Freestream total pressure, psia
Q, q	Freestream dynamic pressure, psf
R.H.	Right Hand
RTV	Room temperature vulcanized

NOMENCLATURE (Concluded)

<u>Symbol</u>	<u>Definition</u>
SEQ	Sequence
SIP	Strain Insulator Pad
X	Longitudinal distance positive, inches aft of test surface leading edge
Y	Lateral distance positive inches right of fixture centerline

REMARKS

All test objectives were met in spite of a failure on the forward FRCI-12 instrumented tile during OA307A in the 11x11-foot tunnel. A portion of the RTV surface layer on this tile debonded and broke off, thus exposing two of the eight pressure tubes being used to measure surface static pressure. Before the damage occurred, data were obtained at Mach 0.78 and 0.80 for the "B" priority runs at a tunnel P_t of 28 inches of mercury. Also, the leading edge of silica tile #56 lifted, causing a 1/4-inch SIP extension.

Table III summarizes the results of leak checks made on the FRCI-12 test article at various times. Those pressure taps that were either plugged or leaking are so noted, and data from these should be considered questionable.

As was previously noted, some tile damage occurred during OA307A. Those data not obtained because of the failure were considered "B" priority. Furthermore, previous test data from test OS55 indicate that the non-dimensionalized tile pressure distribution remains the same regardless of dynamic pressure, and the FRCI-12 venting characteristics are similarly unaffected by changes in dynamic pressure.

CONFIGURATIONS INVESTIGATED

TEST FIXTURES

The 96-0 fixture was used for test OA307A in the 11-foot wind tunnel. The fixture, depicted in Figure 1a, functioned to cause an expansion shock pattern ahead of the specimen, followed by a recompression shock region with attendant positive pressure gradients and high turbulence levels over the test specimen.

The mechanism employed to produce the desired expansion/recompression shocks was a 48-inch span, 15-inch chord flap located at the leading edge of the fixture. The flap was capable of being rotated through angles of zero to 30 degrees by a remotely controlled hydraulic actuator. However, for OA307A, the flap was set at an 18° incidence angle (L.E. down) and was left constant throughout the test.

The fixture was equipped with side plates to make the flow field two-dimensional in the test area. The plates extended from a height of 30 inches above the top of the test panel to 29 inches below the test panel, and were supported from underneath. The beveled leading edges were located 26 inches forward of the test specimen leading edge.

A sealed pressure box enclosed the space under the FRCI-12 panel. This box was vented to the tunnel plenum for this test.

The 81-0 fixture was used to test OA307B in the 9x7-foot wind tunnel.

CONFIGURATIONS INVESTIGATED (Continued)

This fixture, shown schematically in figure 1B, functioned to create a reverse flow region near the boundaries in the flap/surface corner, and the boundary layer separation, together with an unsteady shock wave over the specimen. The flow phenomenon gave rise to large step-type pressure gradients and high turbulence levels.

The fixture was mounted in the ceiling of the tunnel. The flow conditions over the test area were produced by deflecting a 12-inch chord flap with a 100-inch span, located aft of the FRCI-12 test panel. The flap, hinged on the ceiling, could be rotated from zero to 90 degrees by a remotely controlled hydraulic actuator. Test angles included settings from 0° to 55° .

A sealed pressure box enclosed the space behind the FRCI-12 panel. The box was vented to the tunnel test section to permit pressure equalization across the test panels.

TEST ARTICLE

The test article was a flat panel 24-in. by 40-in. long, incorporating three FRCI-12 tiles (two of which, #41 and #48, were instrumented), 17 silica tiles and 15 foam closeout tiles. It was made from the test article used in test OS57. The tile array is shown in figure 1c.

CONFIGURATIONS INVESTIGATED (Concluded)

The other tiles in the array are denoted by S for silica and F for foam. During OA307A the test panel was damaged and a photograph depicting the damage is shown in Figure 2a.

Special fabrication techniques were used to instrument and install the two FRCI-12 instrumented tiles on the panel. A hole was bored through both silica tiles 65 and 46 and the aluminum baseplate, which allowed the adjacent FRCI-12 tile pressure tubes to be routed across the tile gap, through a channel routed on top of the silica tiles and then downward through the hole in the tiles and baseplate. Clearance between tubes and tiles was maintained to allow freedom of tile motion on the SIP. A thin aluminum plate (6 in. by 6 in.) was then bonded to the top of silica tiles 65 and 46 to cover the hole and match the surrounding tile OML. Both FRCI-12 instrumented tiles had a 1/8-in. surface coating of RTV which embedded 8 surface static pressure tubes and also formed the new tile OML.

INSTRUMENTATION

OA307 instrumentation can be categorized as follows:

<u>TYPE</u>	<u># OF PRESSURES</u>	<u>PRESSURES TAP NUMBERS</u>
<u>96-0 Test Fixture (11-Ft)</u>		
Static Pressures	14	101-114 R.H. side looking upstream
Static Pressures	14	201-214 L.H. side looking upstream
Kulites	6	K11-K16 R.H. side looking upstream
<u>81-0 Test Fixture (9x7)</u>		
Static Pressures	16	201-228 R.H. side looking upstream
Static Pressures	8	101-116 L.H. side looking upstream
Kulites	6	K202-223 R.H. side looking upstream
<u>FRCI-12 Test Article</u>		
<u>Tile #41 Pressures</u>		
Surface Statics	8	W101 To W108
SIP	12	S109 To S118, S141, & S142
Internal	10	I119 to I128
GAP	6	G129 To G134
Filler Bar	6	F135 To F140
	42 total	
<u>Tile #48 Pressures</u>		
Surface Statics	8	W201 To W208
SIP	12	S209 To S218, S241, S242
Internal	10	I219 To I228
GAP	6	G229 To G234
Filler Bar	6	F235 To F240
	42 total	

INSTRUMENTATION (Concluded)

All fixture and test article pressures were measured on Rockwell-supplied Scanivalves with Statham transducers. To keep data sampling time short, the pressures were connected to 12, 48-port Scanivalve modules arranged in two packs of 6 modules each with separate solenoid drives. Table IV contains pressure tap I.D. and locations in the FRCI-12 tiles. 96-0 and 81-0 test fixture instrumentation is depicted in Figures 1e and 1f and tabulated in Tables V and VI.

Other instrumentation consisted of a Rockwell-supplied Moog hydraulic servo control system for the flap drive, used for each test fixture. A linear feedback pot provided flap angle information. Ames provided all the power supplies, signal conditioning equipment and tape recorder to monitor and record the Kulite fluctuating pressure transducer signals.

TEST FACILITY DESCRIPTION

The NASA Ames 11-foot Transonic Wind Tunnel is the transonic leg of the Ames Unitary facility. It is a closed-circuit, single-return, continuous-flow, variable-density tunnel. The 11 x 11 x 22-foot test section is slotted to permit transonic testing. The nozzle has adjustable sidewalls. The tunnel air is driven by a 3-stage axial flow compressor powered by four wound-rotor induction motors. The speed of the motors is varied as necessary to provide the desired Mach number. The motors have a combined output of 180,000 horsepower for continuous operation or 216,000 horsepower for one hour. Tunnel temperature is controlled by aftercoolers and a cooling tower. Four 30,000 cubic-foot storage tanks provide dry air for tunnel pressurization.

The tunnel can be operated at nominal Mach numbers of 0.5 to 1.4, Reynolds numbers per foot $\times 10^{-6}$ of 1.7 to 9.4, dynamic pressure (PSF) of 150 to 2,000 and a total temperature ($^{\circ}\text{R}$) of 540 to 610, respectively.

This tunnel is used for force and moment, pressure internal air flow-inlet, and dynamic stability tests.

The Ames 9 x 7-foot Supersonic Wind Tunnel is a variable-density, continuous-flow type with an adjustable nozzle to permit supersonic testing over a Mach number range continuously variable from 1.5 to 2.5. The nozzle is of the asymmetric, sliding-block type in which the variation of the test section Mach number is achieved by translating, in the stream-wise direction, the fixed-contour block that forms the floor of the nozzle.

TEST PROCEDURES

NASA/ARC crews installed the 96-0 and 81-0 test fixtures in their respective tunnels before each test began. While ARC crews hooked up fixture hydraulics, Rockwell personnel hooked up test fixture and test article instrumentation including Scanivalves, Kulites, and pressure tubing.

In each fixture, the test article was installed using the necessary spacer and shims, with ANF 5/16-24 and ANC 1/4-20 socket-head cap screws 6.25 inches long. The completed installation placed the leading edge of the test article flush within the test fixture. Figures 1a and 1b show the two installations.

Foam rubber strips were placed in the cavities under the fixture side-cover plates in order to avoid the possibility of a reverse flow pattern developing which might affect flow characteristics on or around the test article.

In-tunnel calibrations of test instrumentation were performed next. For OA307A in the 11-foot tunnel, the flap was check calibrated at only 18° where it was fixed for the entire test. Flap calibrations in the 9x7 (for OA307B) were performed between 0° and 60° . For both tests, the Kulite transducers in the test fixtures were check calibrated at ± 1 psi prior to the test.

The test procedure during OA307A was to first pump the tunnel down to a total pressure of 25 inches of mercury for a Scanivalve check. After

TEST PROCEDURES (Continued)

tunnel drive start, the tunnel total pressure was pumped down to 22 inches of mercury. Next, the video recorder and Kulite recorder were turned on. The Mach number was established at 0.78 and a steady-state data point was taken.

With the tunnel total pressure constant at 22 inches of mercury, data were taken at each 0.02 Mach number increment up through 0.88, and then at each Mach number increment down to 0.78. The tunnel total pressure was then changed to 28 inches of mercury and data were taken at Mach 0.78 and 0.80. This Mach number sweep was not completed and the tunnel was shut down (fast stop) because the panel was damaged as observed on the video screen.

The test procedure during OA307B was to first pump the tunnel down to a total pressure of 25 inches of mercury for a Scanivalve check. Next, the tunnel total pressure was pumped down to 5 inches of mercury, and the tunnel drive was started with the Mach number set at 1.55. The tunnel air was then purged at Mach 1.80. The test fixture flap angle was set at zero degrees.

Data were taken when the tunnel total pressure was 23.70 inches of mercury and the test fixture flap angle was zero degrees. Data were taken at each of these flap angles: 0, 15, 30, 35, 37.5, 40, 42.5, 45, 50, 52, 55, 52, 50, 45, 42.5, 40, 37.5, 35, 30, 15, and 0. The tunnel total pressure was then changed to 30.89 inches of mercury and data were taken at each of the flap angles noted above.

The Scanivalves had malfunctioned when data were being collected at a

TEST PROCEDURES (Concluded)

tunnel total pressure of 23.70 inches of mercury. Therefore, data were again collected at each flap angle noted above. Next, the tunnel was shut down and the test article was inspected.

DATA REDUCTION

Standard tunnel equations were used to compute all tunnel conditions. Local static pressure data were reduced to standard coefficient form,

$$C_p = (P_\ell - P_\infty) \times 144/q$$

Typical plotted data are shown in Figure 3.

REFERENCES

1. STS82-0368, "Pretest Information for Space Shuttle FRCI-12 TPS Tile Venting Tests OA307A/B in the Ames Research Center (ARC) 11x11-Ft. and 9x7-Ft. Wind Tunnels," May 1982.

TABLE I

TEST : OA307A		DATE : 5-27-82	
TEST CONDITIONS			
MACH NUMBER	REYNOLDS NUMBER (per unit length)	DYNAMIC PRESSURE (pounds/sq. inch)	STAGNATION TEMPERATURE (degrees Fahrenheit)
0.78	2.71×10^6	443	120
0.80	2.74×10^6	460	
0.82	2.78×10^6	472	
0.84	2.81×10^6	485	
0.85	2.83×10^6	494	
0.86	2.84×10^6	496	
0.87	2.85×10^6	507	
0.88	2.87×10^6	509	↓
0.78	3.44×10^6	568	120
0.80	3.52×10^6	581	120

BALANCE UTILIZED: NA

	CAPACITY:	ACCURACY:	COEFFICIENT TOLERANCE:
NF	<u> </u>	<u> </u>	<u> </u>
SF	<u> </u>	<u> </u>	<u> </u>
AF	<u> </u>	<u> </u>	<u> </u>
PM	<u> </u>	<u> </u>	<u> </u>
RM	<u> </u>	<u> </u>	<u> </u>
YM	<u> </u>	<u> </u>	<u> </u>

COMMENTS:

TABLE I (Concluded)

[illegible]

TABLE II

TEST: OA-307A (ARC 11-Ft)										DATE: MAY 27, 1982									
CONFIGURATION				SCHD.		PARAMETERS/VALUES		MACH NUMBERS (OR ALTERNATE INDEPENDENT VARIABLE)											
				α	β	FLAP	P_t (in Hg)	M=	0.78	0.80	0.82	0.84	0.85	0.86	0.87	0.88			
FRCI-12 TILE																			
PANEL IN																			
RUN#					18°		22												
2			(ND-8)																

TABLE II (Concluded)

[illegible]

TABLE III

LEAK CHECK SUMMARY

<u>DATE</u>	<u>TYPE CHECK</u>	<u>TAPE#</u>	<u>CONDITION</u>	<u># OF TEST AFFECTED</u>
5/17/82	continuity	I127	partial plug	before ship
5/17/82	continuity	S213	partial plug	ment from
5/17/82	continuity	I222	partial plug	Downey to
5/17/82	continuity	I224	partial plug	AMES
5/17/82	continuity	I225	plugged	OA-307A/B
6/23/82	leak	W106	slow leak	OA-307B
6/23/82	leak	W108	leak	
6/23/82	leak	W205	partial plug	
6/23/82	leak	I219	leak	
5/27/82	leak	113 (fixture)	leak	OA-307A
5/27/82	leak	212 (fixture)	leak	

TABLE IV. COORDINATES OF PRESSURE TAPS IN AND UNDER FRCI-12 TILES

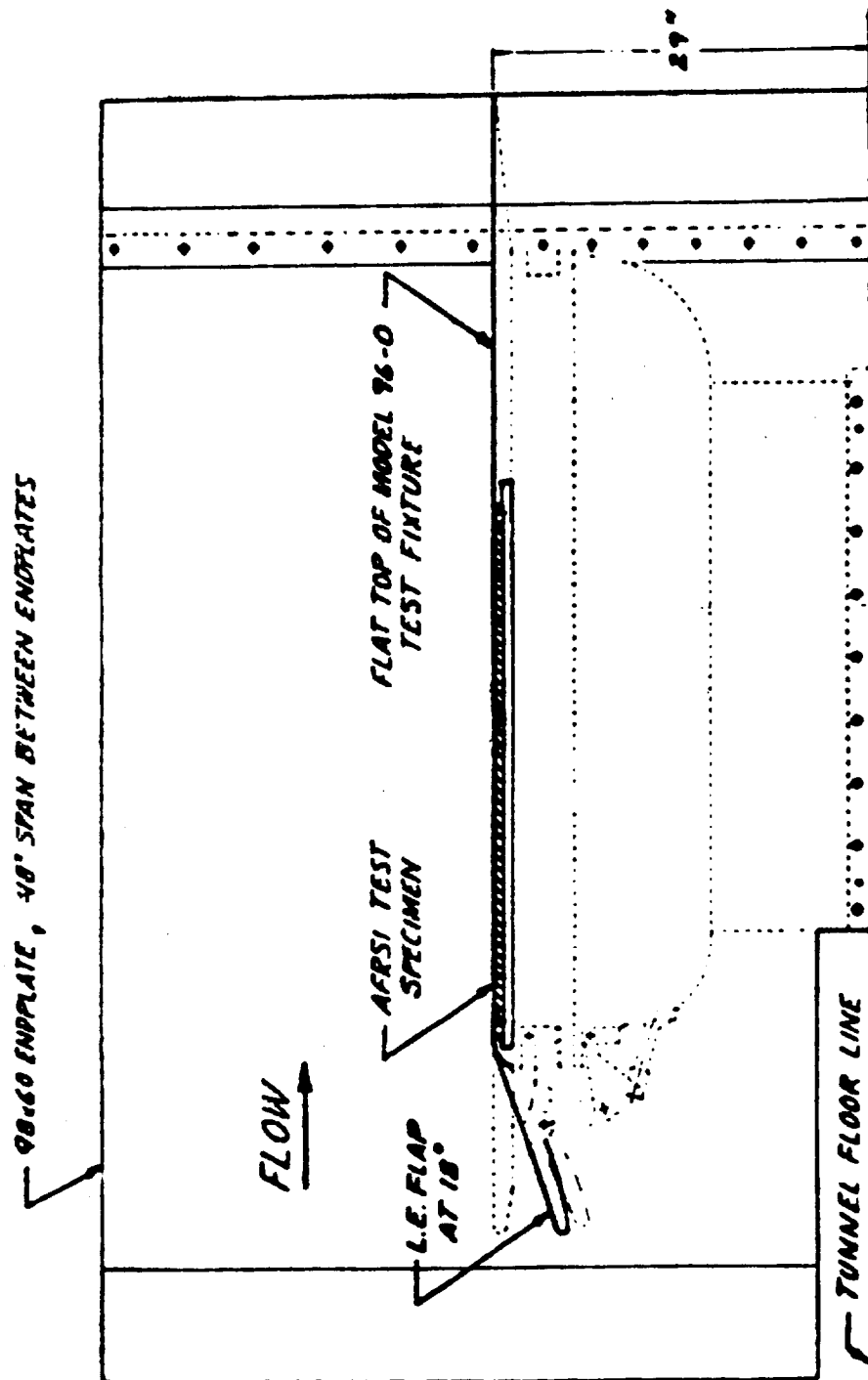
Y_T	0.40	1.06	1.10	2.12	2.24	2.60	3.10	3.40	4.24	4.90	5.30	5.80	6.24	6.36	7.30	7.42	8.00
3.19									(1) X20								
3.10							(F) X35				(6) X30						
2.30								(5) X13		(5) X14							
2.12				(6) X29										(F) X37			
1.50						(1) X25			(1) X26			(1) X27					
1.06		(F) X35														(6) X31	
0.75					(5) X09			(5) X10		(5) X11			(5) X12				
0.00	(H) X01		(H) X02 (S) X41		(H) X03			(H) X04		(H) X05			(H) X06		(H) X07 (S) X42		(H) X08
-0.75					(1) X19			(1) X20		(1) X21			(1) X22				
-1.06		(F) X40														(6) X32	
-1.50						(5) X15			(5) X16			(5) X17					
-2.12				(6) X34										(F) X30			
-2.30								(1) X23		(1) X24							
-3.10							(F) X39				(6) X33						
-3.19									(5) X18								

TABLE V. 96-0 PRESSURE INSTRUMENTATION LOCATIONS

X \ Y	STATIC TAPS						Kulites at Y=16
		-16		0		16	
0		201				101	
1		202				102	
2		203				103	
4		204				104	
6		205				105	K11
8		206				106	
10		207				107	K12
12		208				108	
14		209				109	K13
16		210				110	
18		211				111	K14
20		212				112	
24		213				113	K15
30							K16
36		214				114	

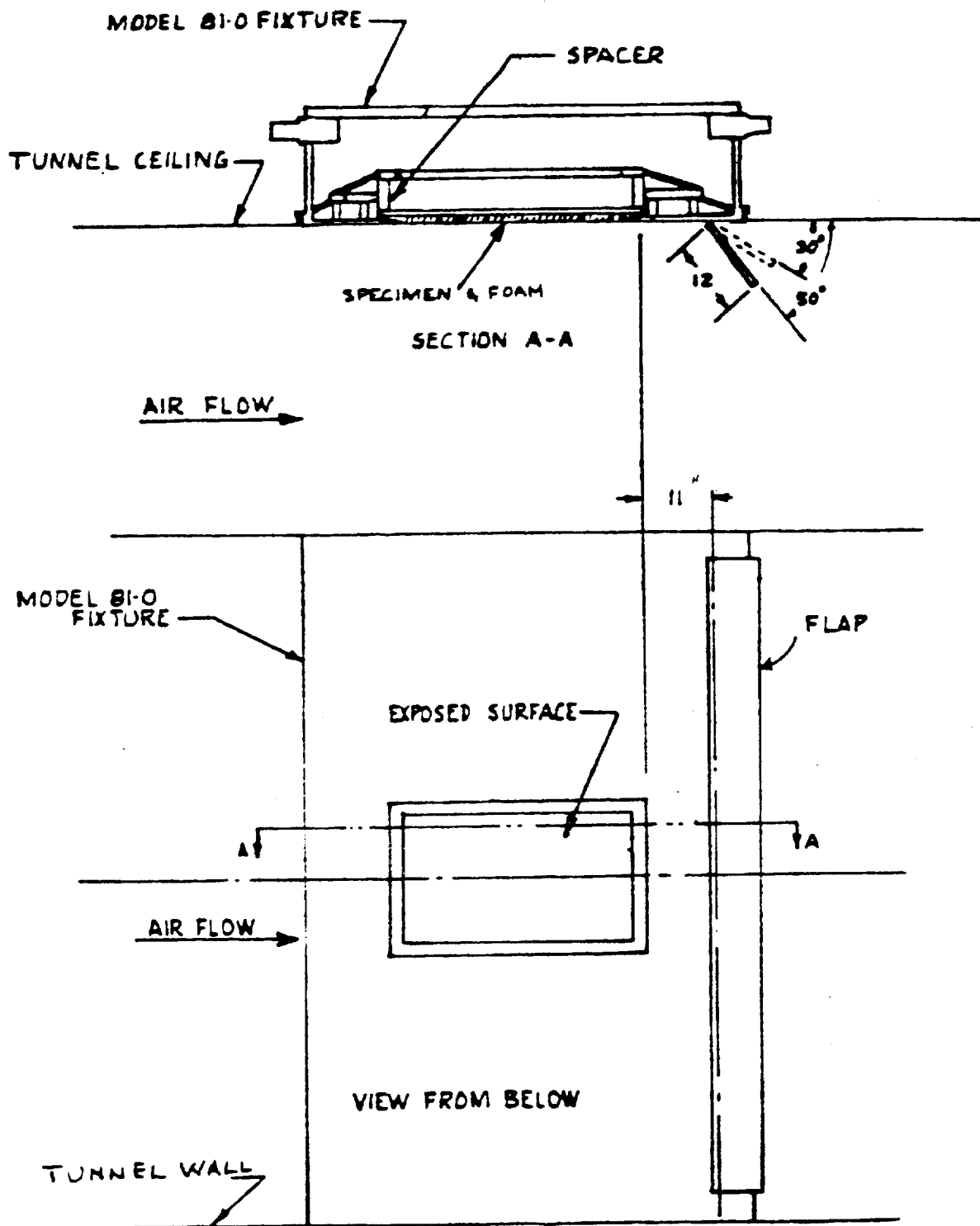
TABLE VI. 81-0 PRESSURE INSTRUMENTATION LOCATIONS

X \ Y		-14.62	14.62
		STATIC TAPS	
2		101	201
6		103	203
10		105	205
12			207
14		107	209
16			211
18		110	213
20			215
22		113	217
24			219
26		115	221
28			222
30			224
32			225
34			227
36		116	228
		KULITES	
5			K21
9			K22
13			K24
17			K26
23			K29
29			K31



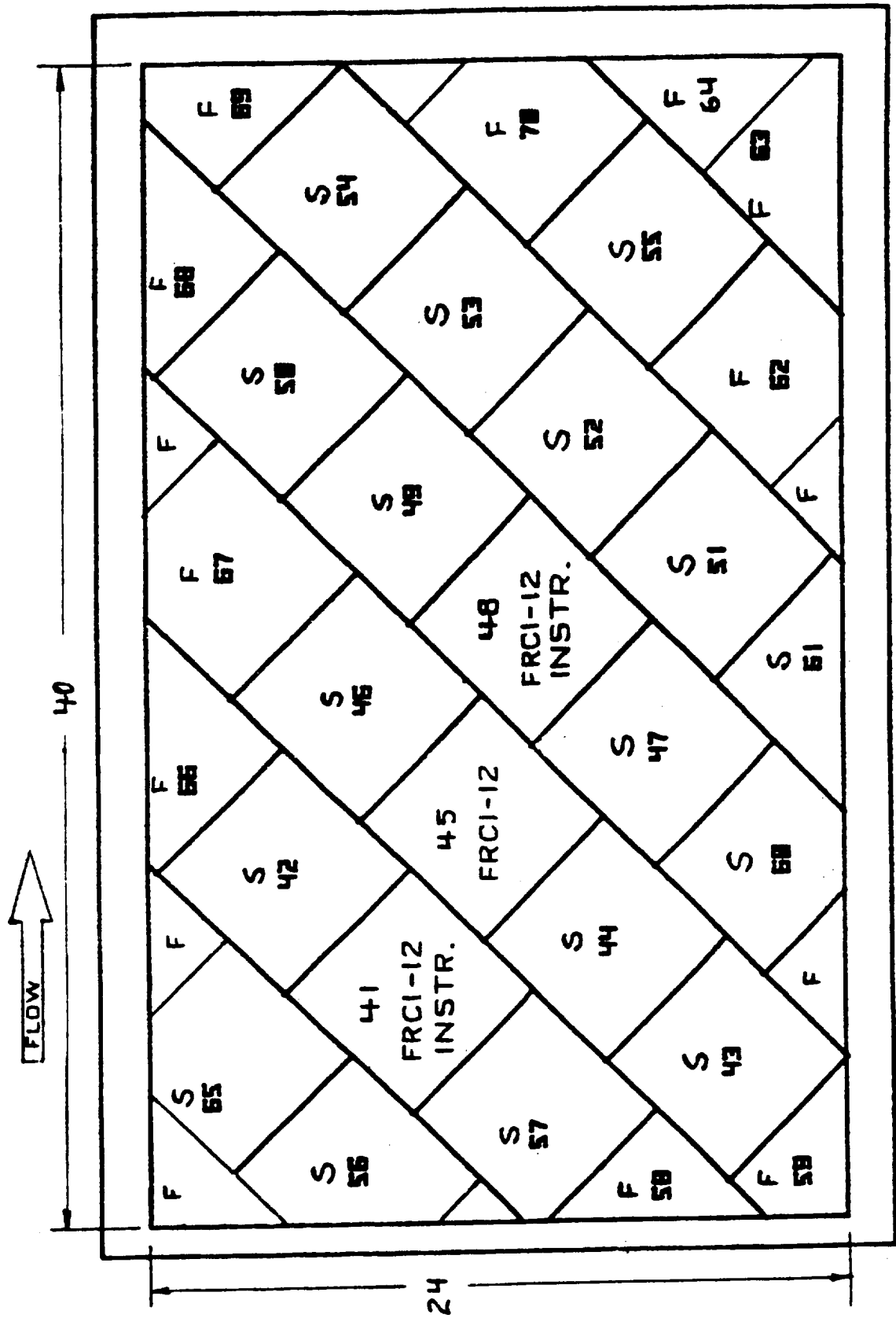
a. Fixture 96-0

Figure 1. Model Sketches



b. Fixture 81-0

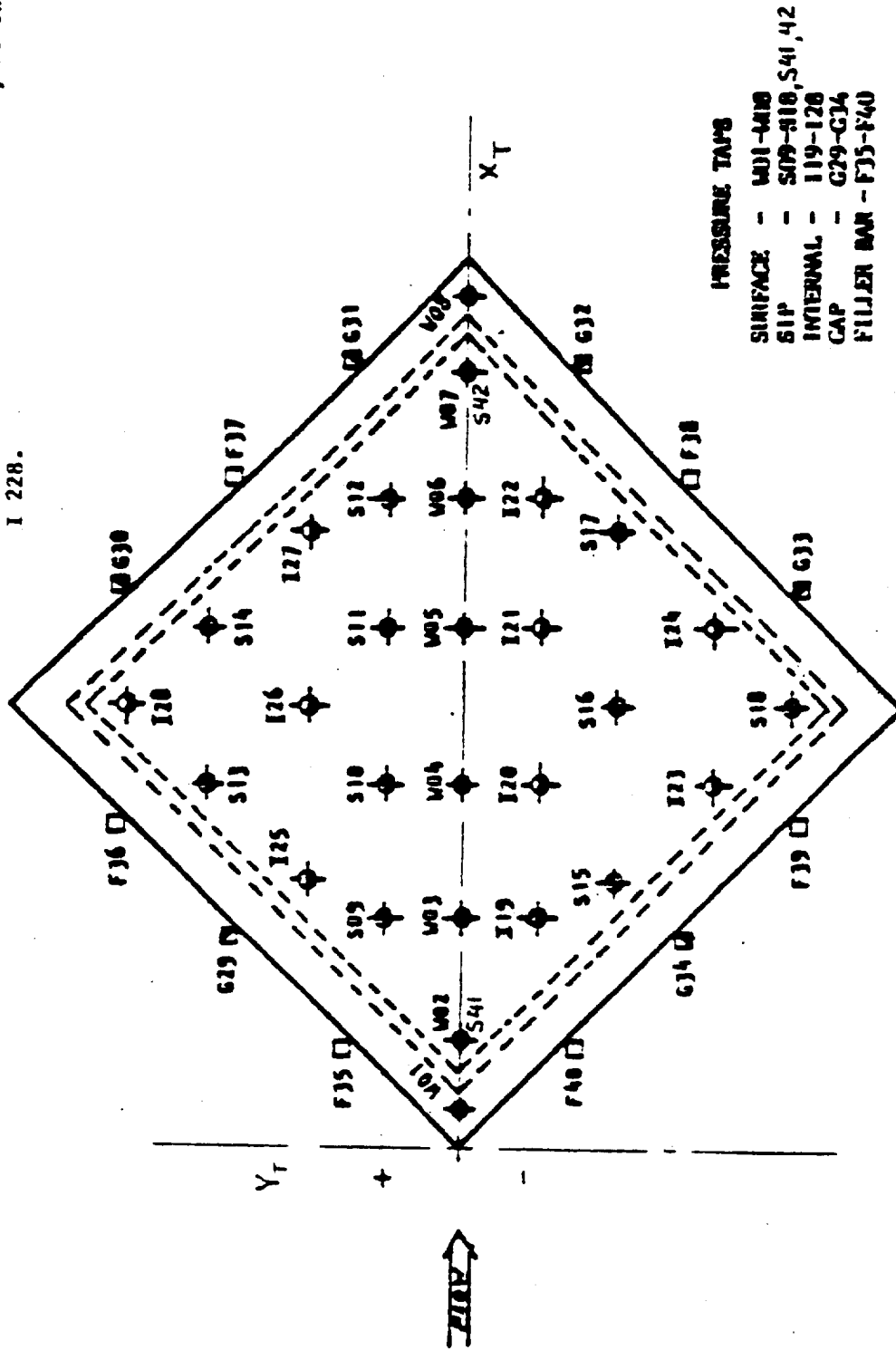
Figure 1 (Continued)



c. TILE LAYOUT-FRCI-12 TEST ARTICLE (ND-8)

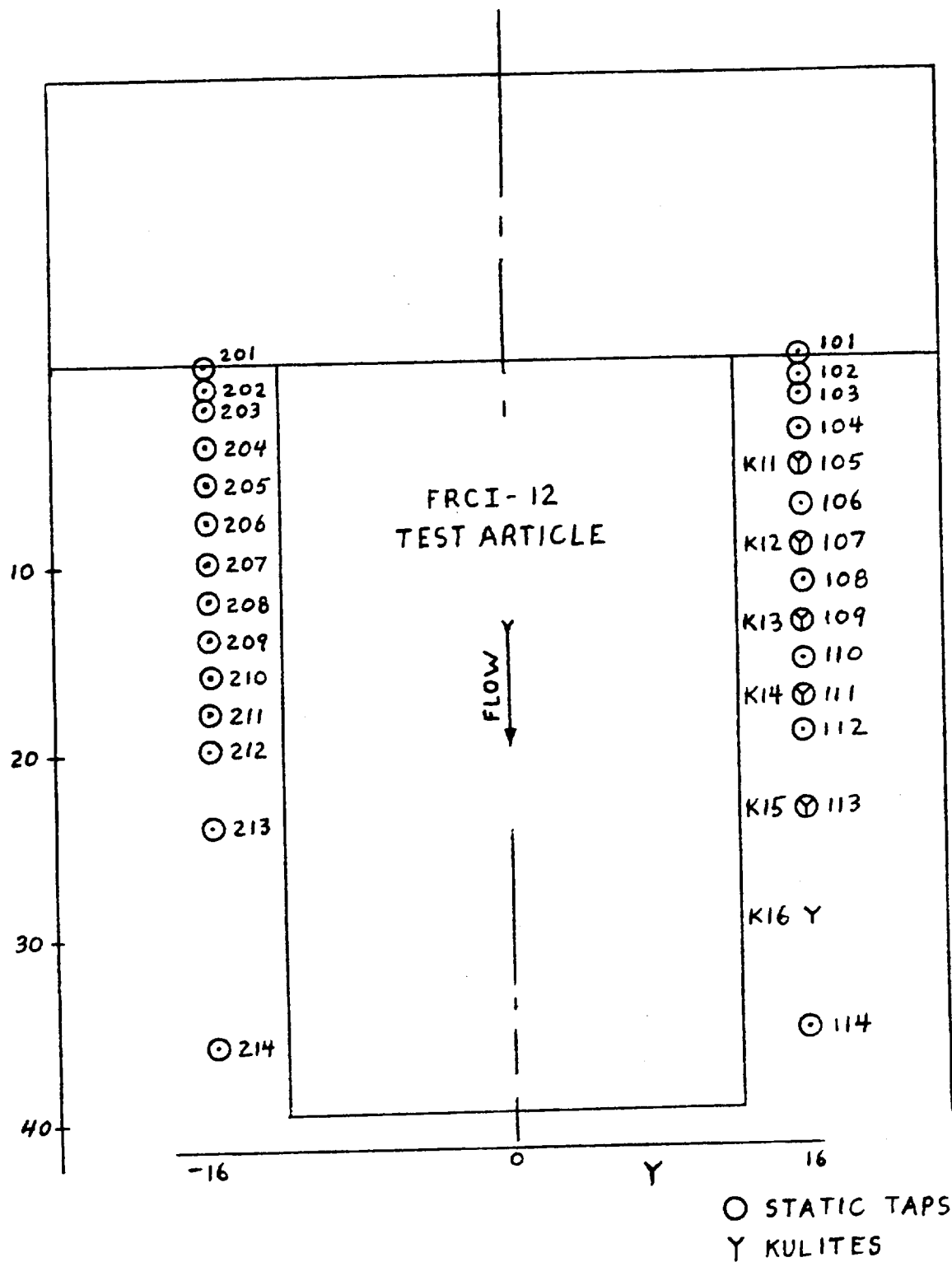
Figure 1 (Continued)

Tiles numbered 41 and 48 have this pressure tap arrangement. Taps on Tile 41 have the added numeral 1, as in I 128, and taps in Tile 48 have the added numeral 2, as in I 228.



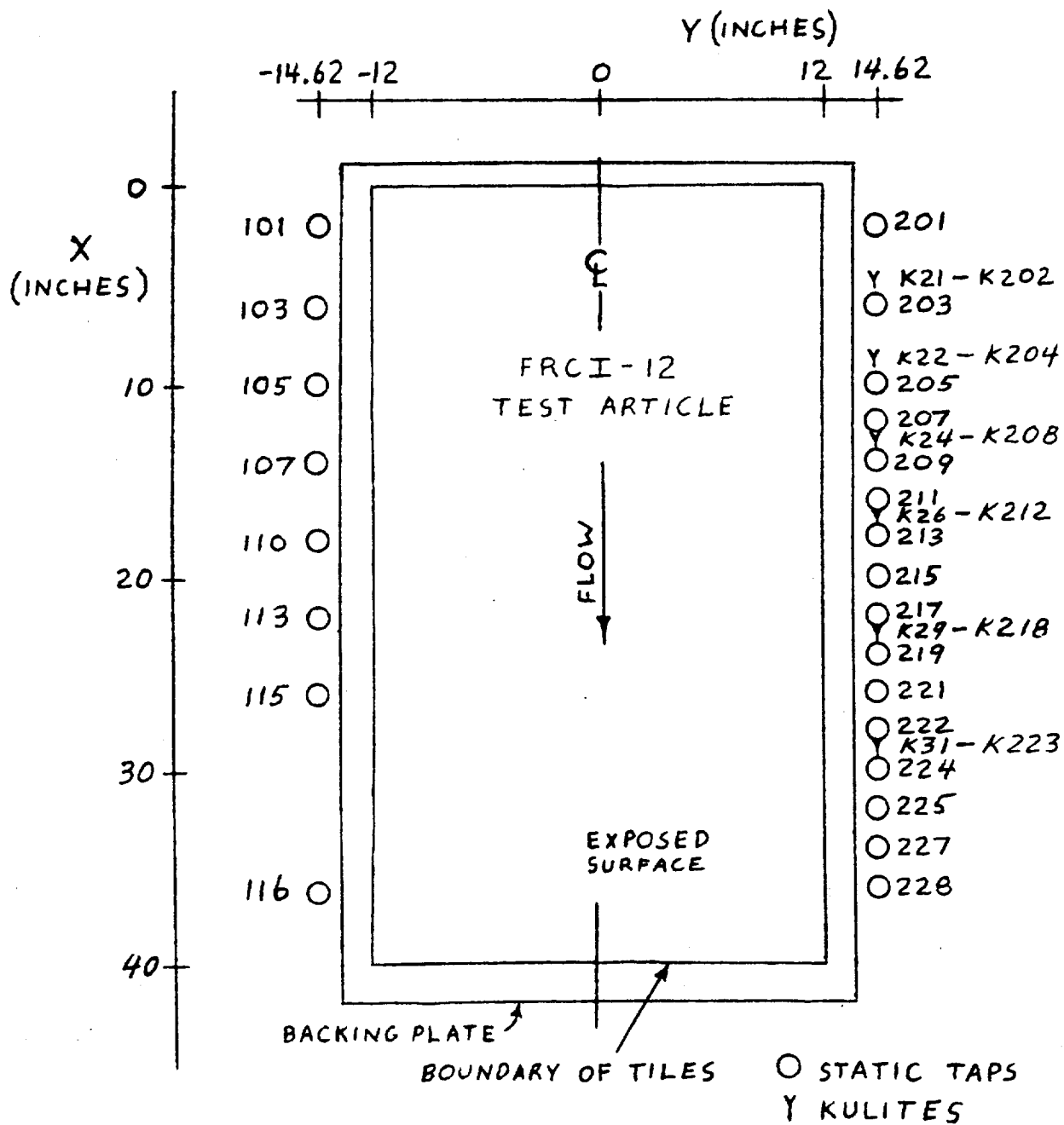
d. PRESSURE TAP LOCATION IN AND UNDER PRCI-12 TILE

Figure 1 (Continued)



e. INSTRUMENTATION LOCATIONS - MODEL 96-0 FIXTURE (OA307A)

Figure 1 (Continued)



f. INSTRUMENTATION LOCATIONS - MODEL 81-0 FIXTURE (OA307B)

Figure 1 (Concluded)

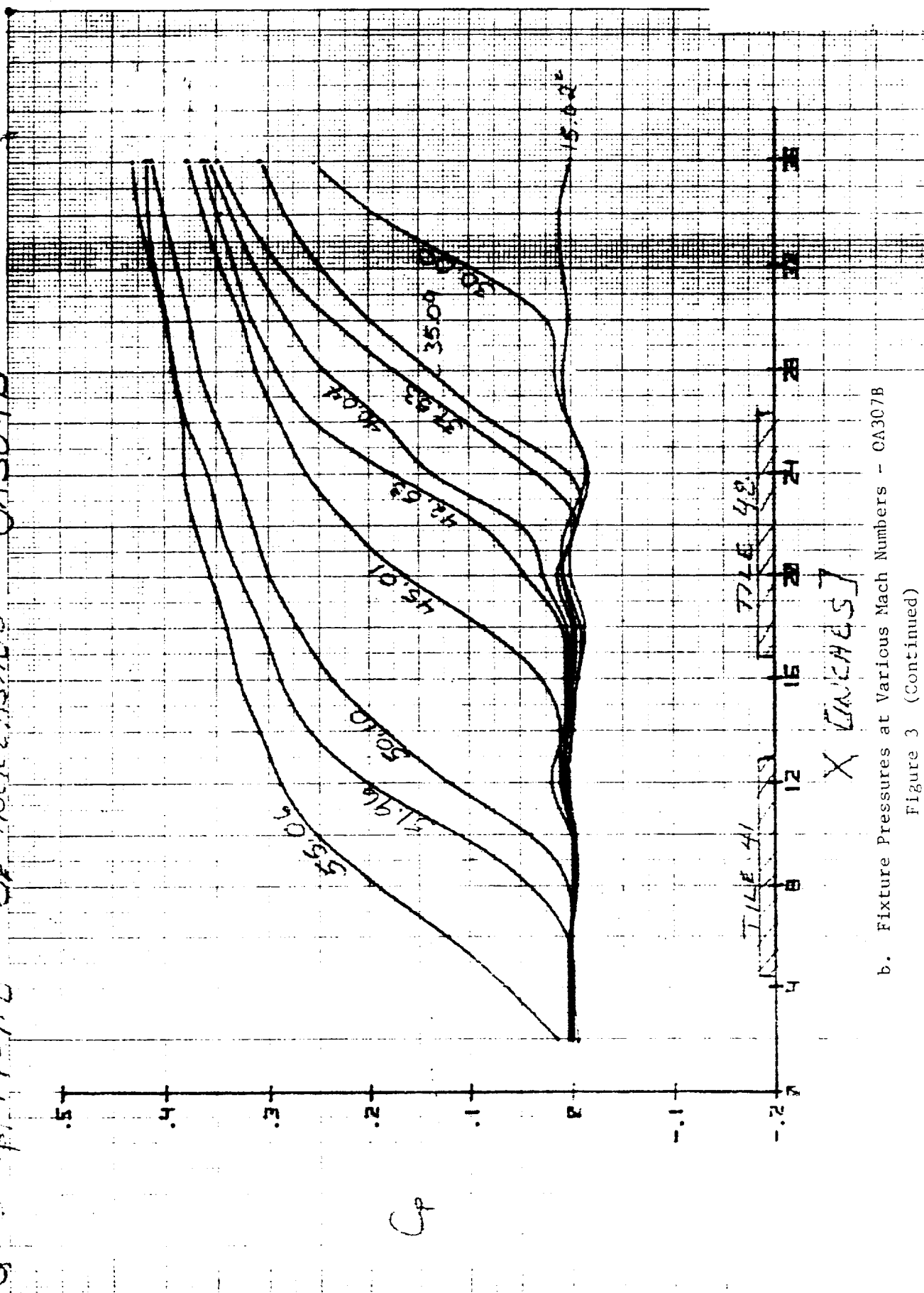


a. Damaged Instrumented Tile #41

Figure 2. Model Photograph

DATA FIGURES

Q: 8000 ft M=1.8 S_F INCREASING OA307B

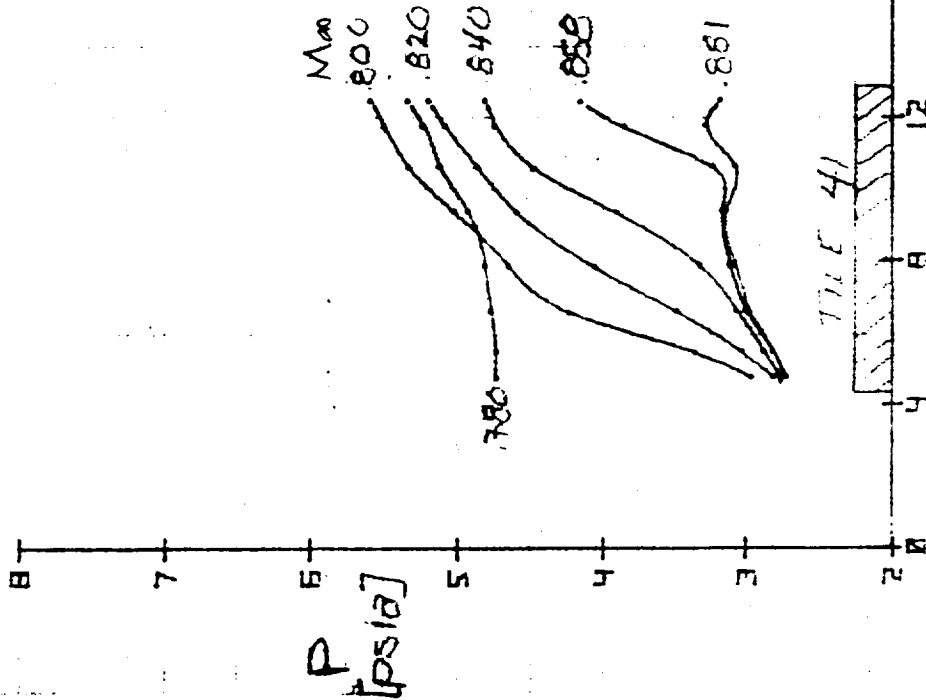


b. Fixture Pressures at Various Mach Numbers - OA307B

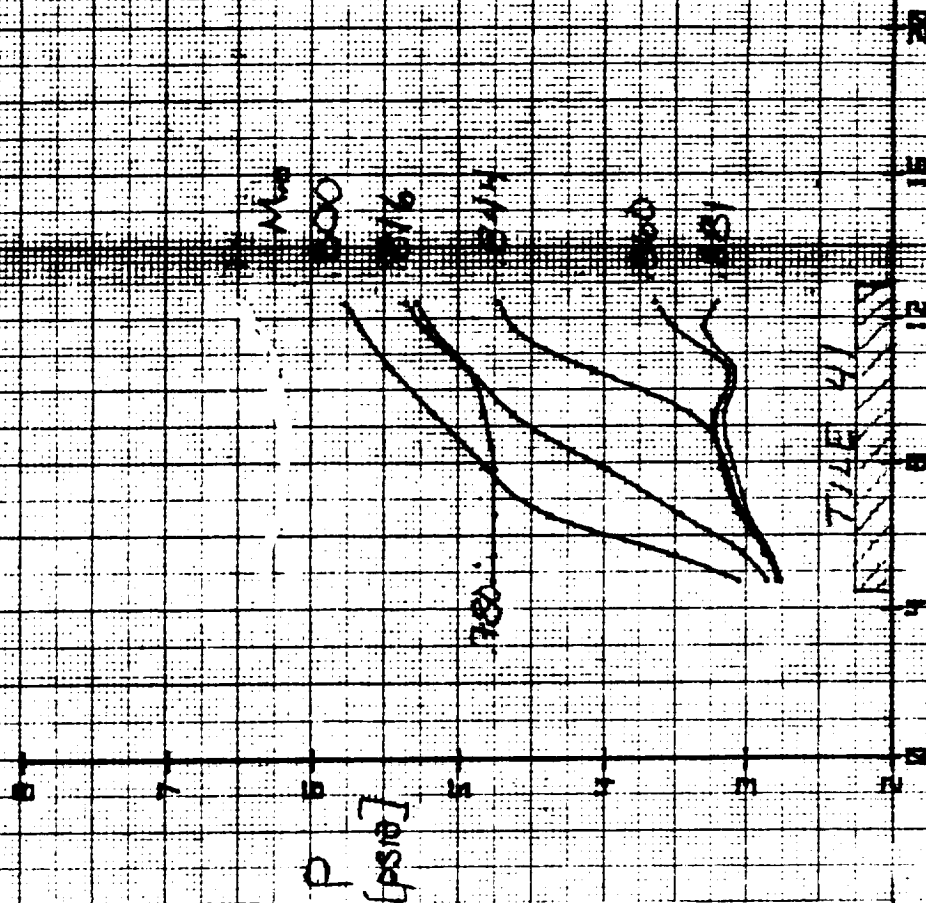
Figure 3 (Continued)

OA307A
INCREASING MACH NUMBER

$$\delta_{FLAP} = 18^\circ$$



DECREASING MACH NUMBER



X [INCHES]

c. Tile Surface Pressures at Various Mach Numbers - OA307A

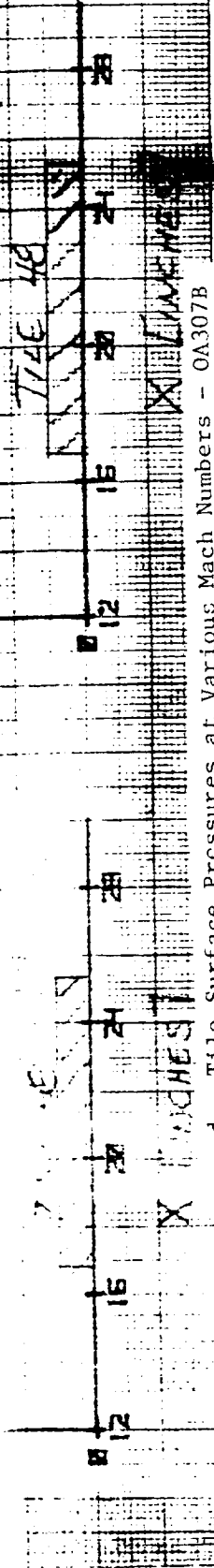
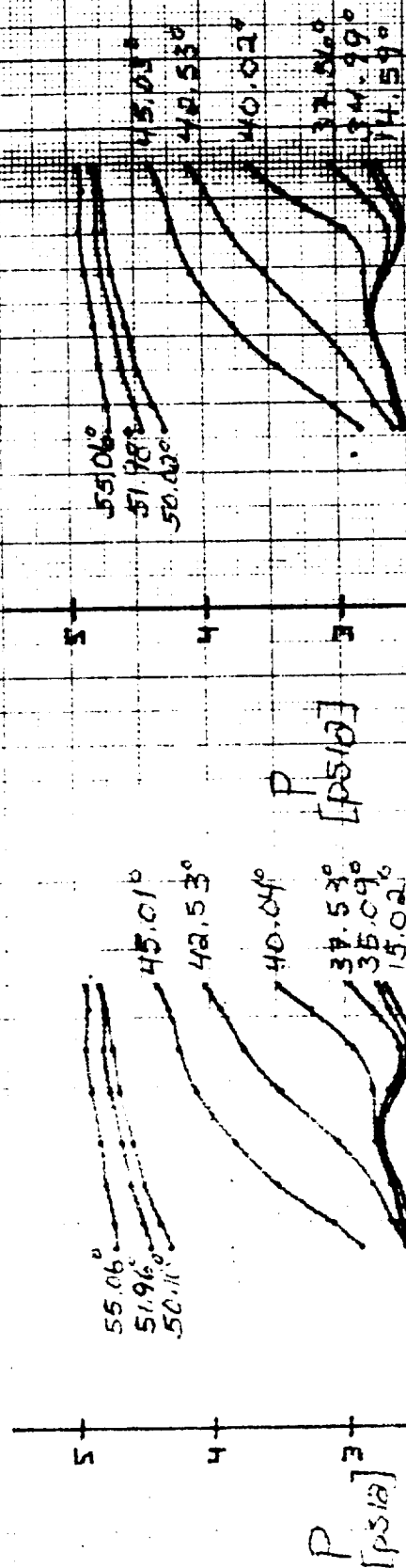
Q = 860 psf

M = 1.8

OA307B

FLAP ANGLE DECREASING

FLAP ANGLE INCREASING

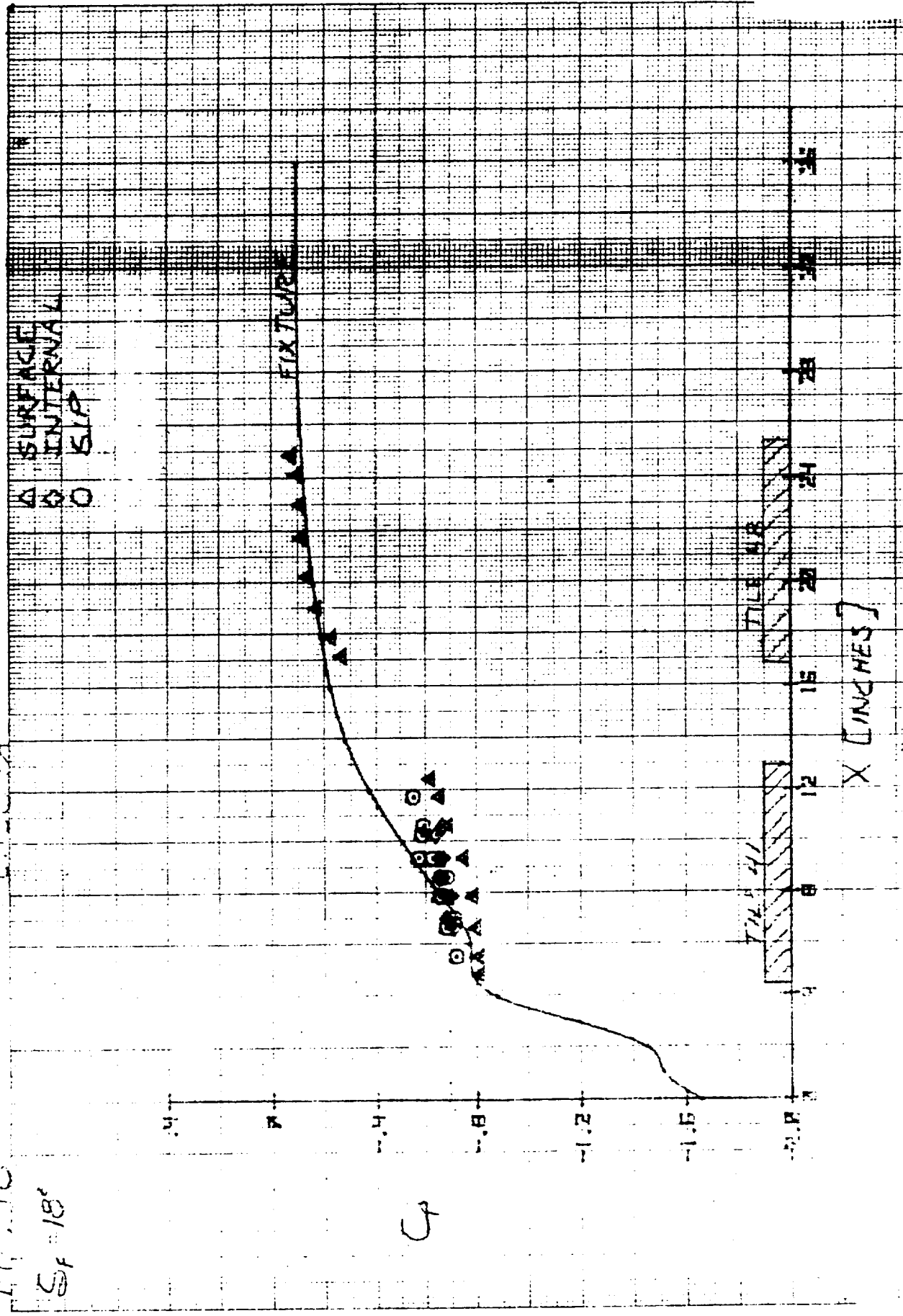


d. Tile Surface Pressures at Various Mach Numbers - OA307B

Figure 3 (Continued)

0.78

$M_0 = 1.0$
 $S_F = 18^\circ$



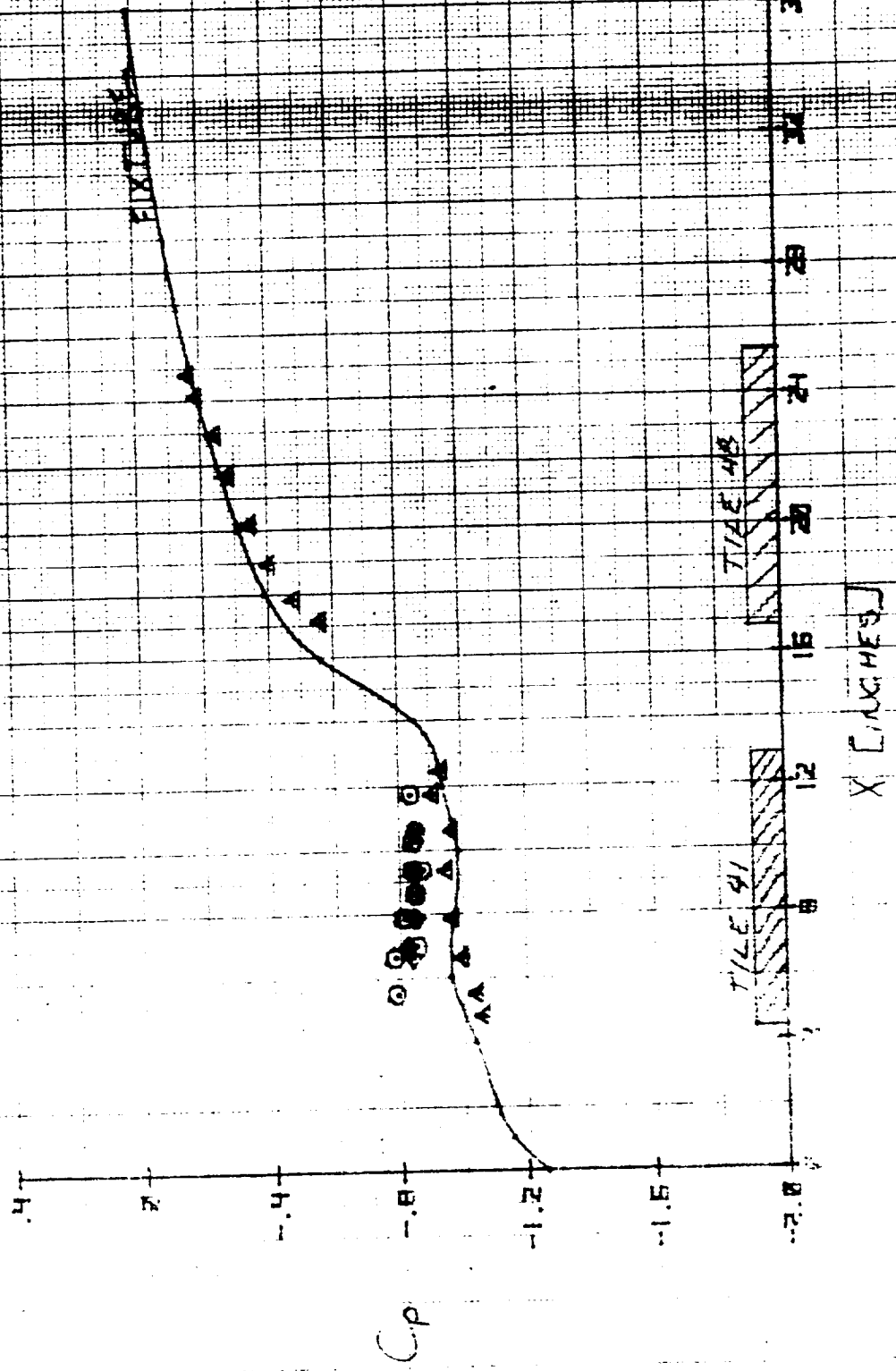
e. Fixture, Tile Surface, Internal and SIP Pressures at $M = 0.78 - OA307A$

Figure 3 (Continued)

LA 307A

M = .881
 $\delta = 15^\circ$

△ SURFACE
 ○ INTERNAL
 ○ SIP



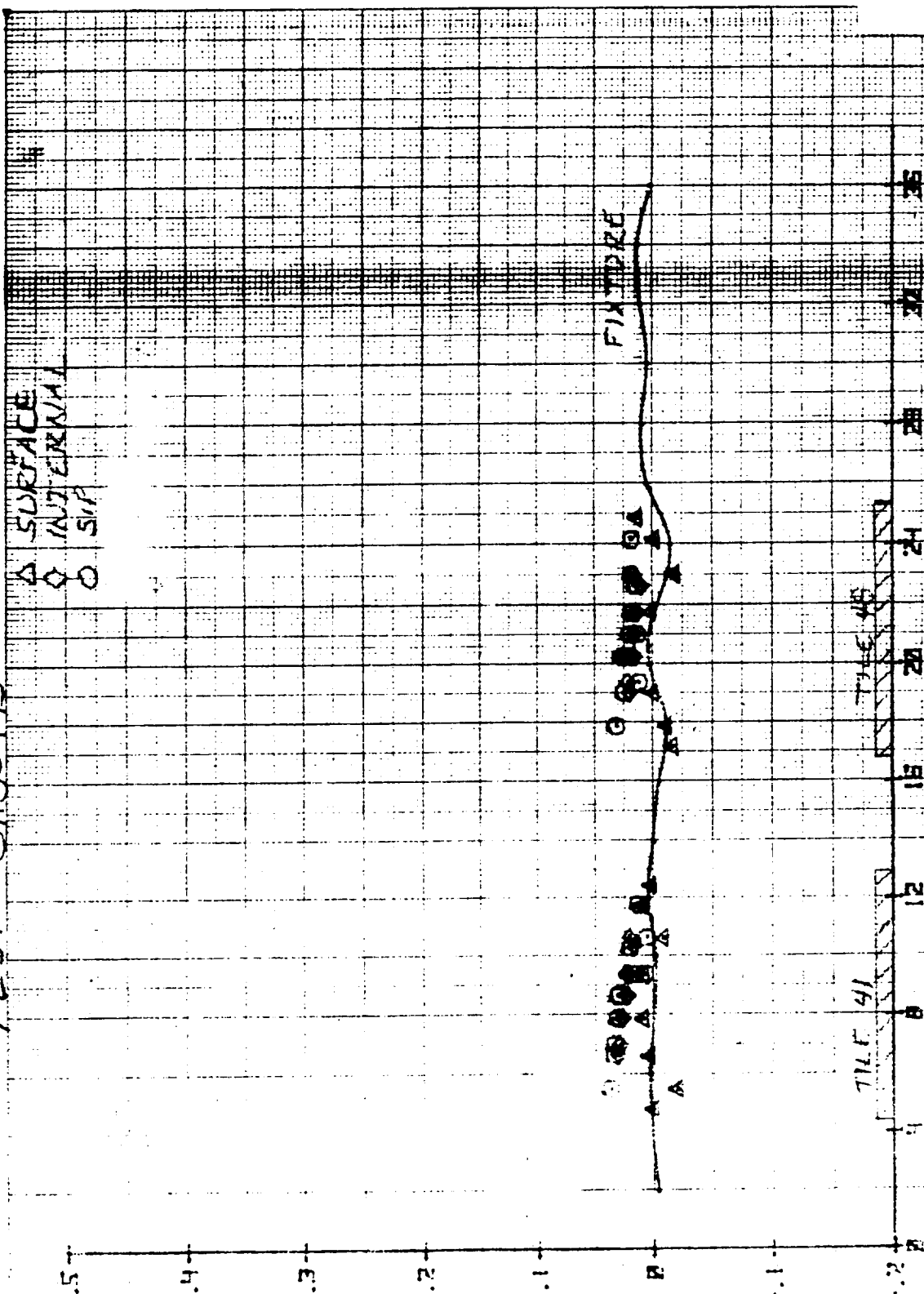
f. Fixture, Tile Surface, Internal and SIP Pressures at $M = .881 - OA307A$
 Figure 3 (Continued)

$\delta_f = 15.02^\circ$

$M = 1.8$

TEST OA307B

△ SURFACE
○ INTERNAL
○ SIP



g. Fixture, Tile Surface, Internal and SIP Pressures at $M = 1.8, \delta_f = 15.02^\circ$ - OA307B

Figure 3 (Continued)

CA-307B

$S_f = 55.06^\circ$

$M = 1.8$

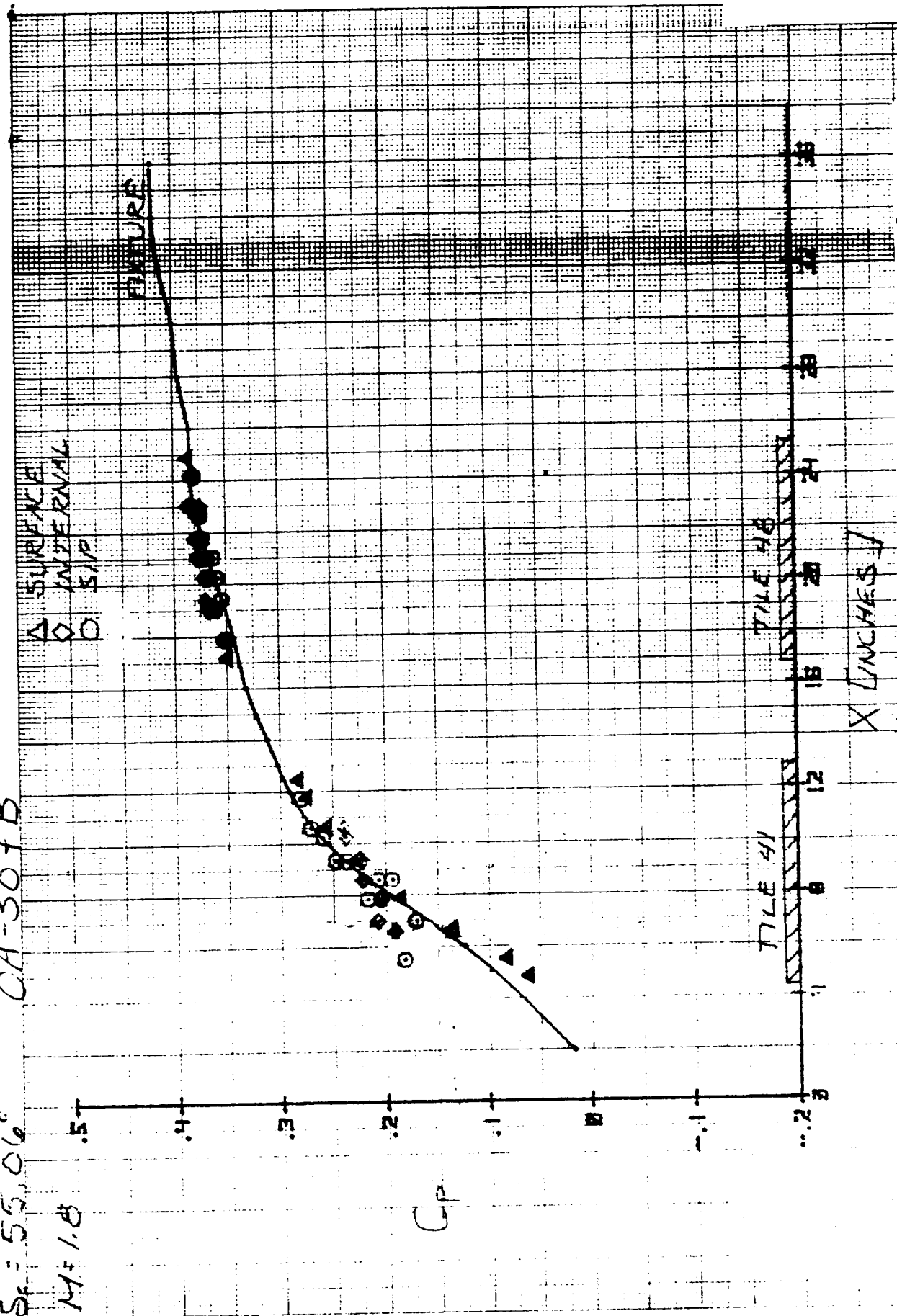
△ SURFACE
○ INTERNAL
○ SIP

FIXTURE

TILE 48

TILE 41

X [INCHES]

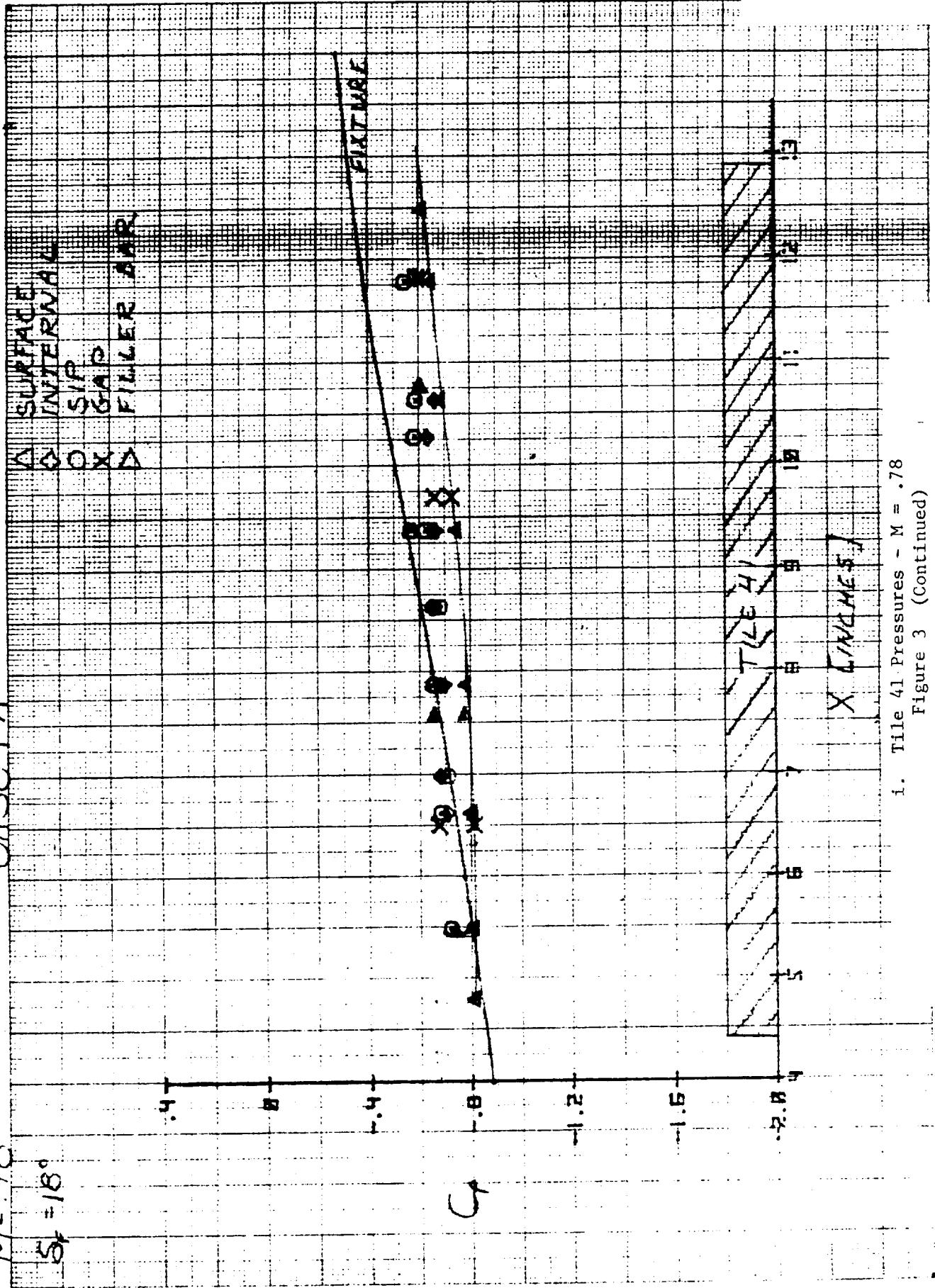


h. Fixture, Tile Surface, Internal and SIP Pressures at $M = 1.8, \delta_F = 55.06^\circ$ - OA307B

Figure 3 (Continued)

$M = 7.8$
 $\alpha = 18^\circ$

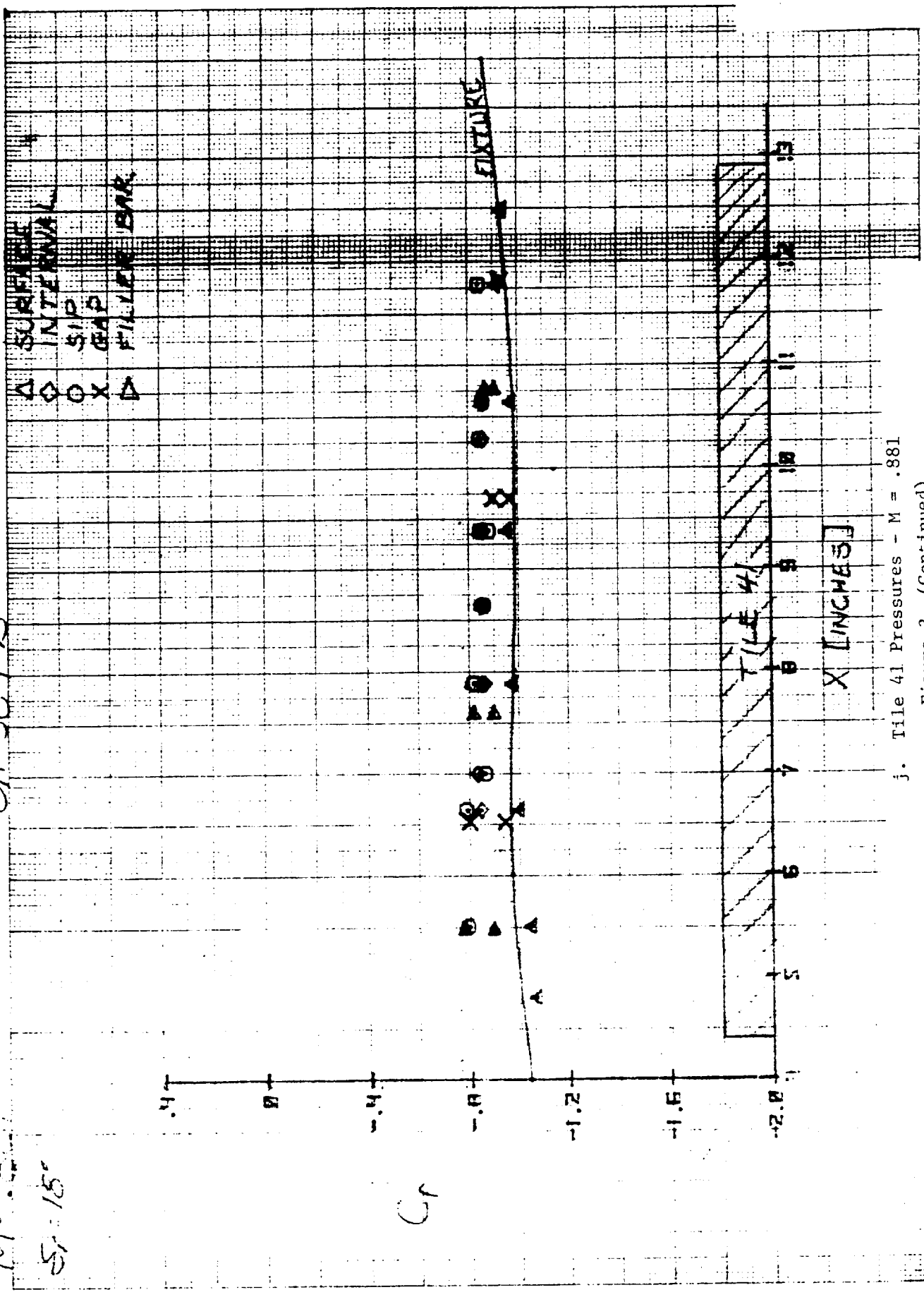
0A307A



i. Tile 41 Pressures - $M = .78$
 Figure 3 (Continued)

OA-307B

M = .981
S = 15°



j. Tile 41 Pressures - M = .981

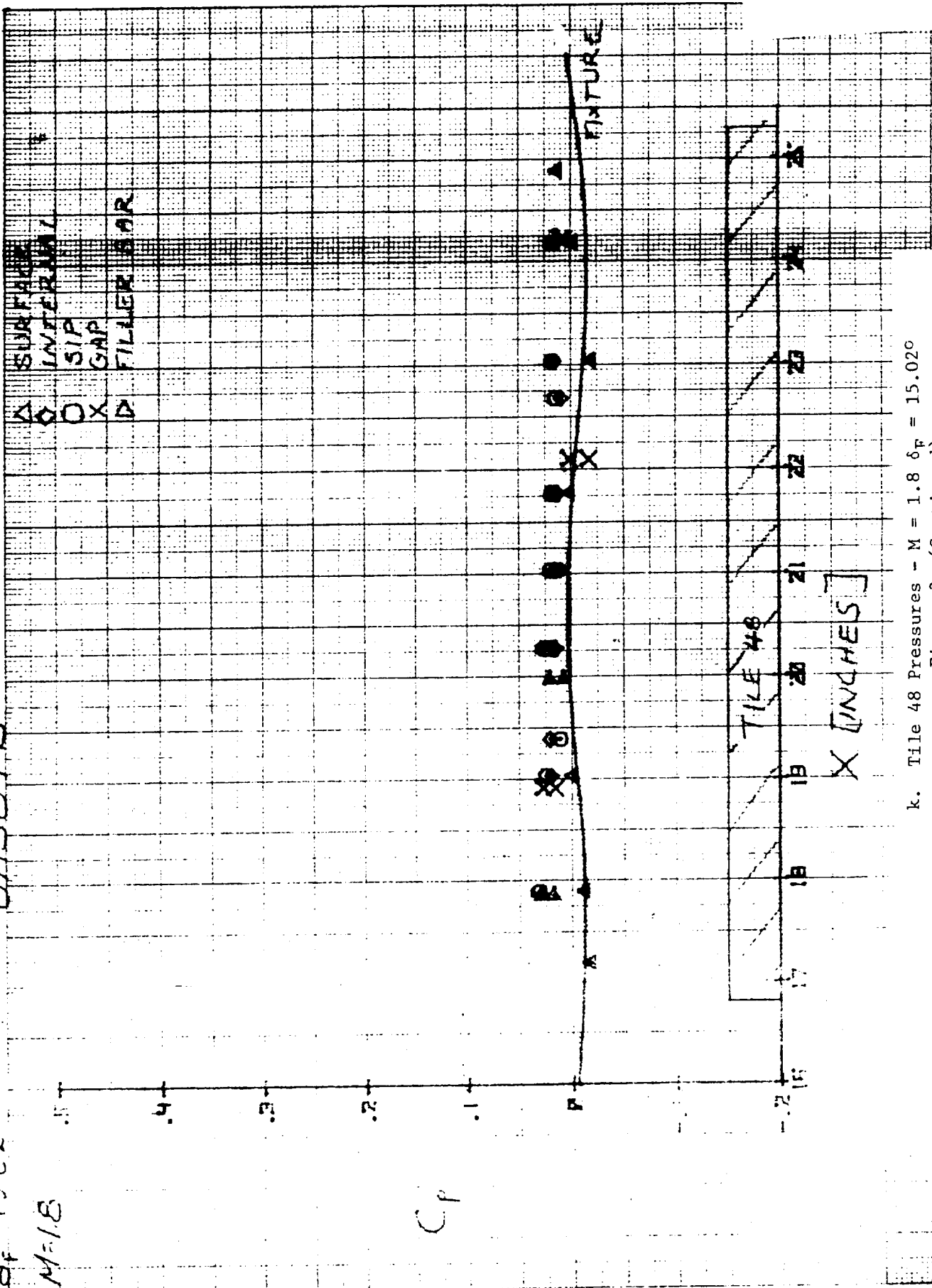
Figure 3 (Continued)

$\delta_F = 15.02^\circ$

0A307B

$M = 1.8$

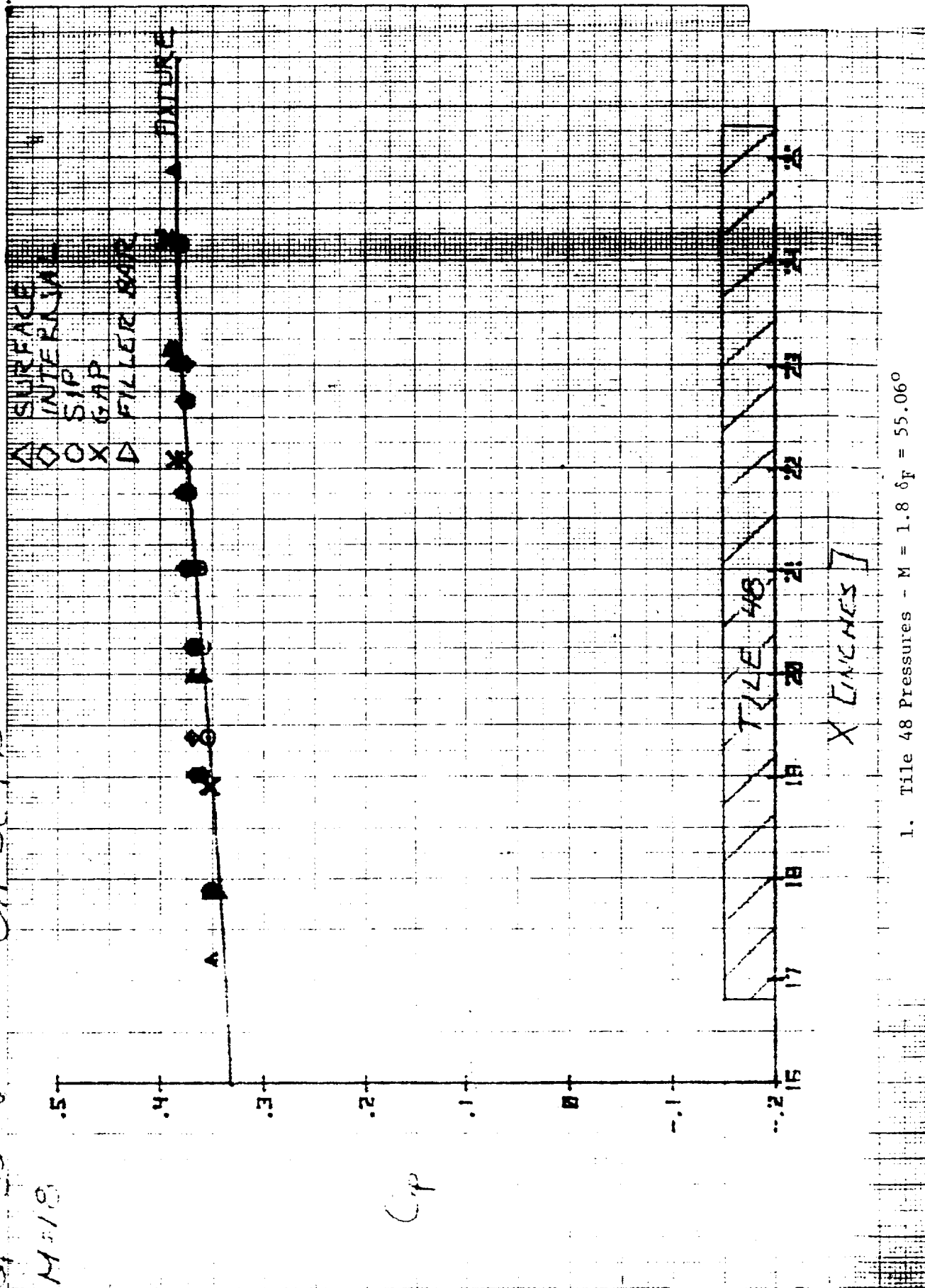
C_p



k. Tile 48 Pressures - $M = 1.8$ $\delta_F = 15.02^\circ$
Figure 3 (Continued)

OA-307B

$S_f = 0.516$
 $M = 1.8$



1. Tile 48 Pressures - $M = 1.8$ $\delta_F = 55.06^\circ$

Figure 3 (Concluded)

$M = 1.80$
 $S_F = 18^{\circ}$

0A-307A

A DISTANCE FROM
 TILE-SIP BOUNDARY LINE

□ 11 INCH
 ○ 30 INCH
 X 70 INCH

4
 8
 12
 16
 20

CP

7 8 9 10 11 12 13
 TILE 41
 X [INCHES]

a. Tile 41 $M = 0.80$

Figure 4. Tile Internal Pressures

0.1-307A

$M = .84$

$S_F = 18^\circ$

C_p

Z DISTANCE FROM
TILE-SIP BOND LINE

□ .11 INCH
○ .30 INCH
X .70 INCH

-.4
-.8
-1.2
-1.6
-2.0

TILE 41
X [INCHES]

b. Tile 41 $M = 0.84$
Figure 4 (Continued)

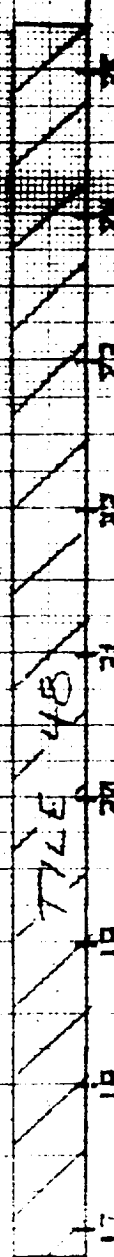
$S_F = 40.04^\circ$ OA-30713

$M = 1.8$

C_p

Z DISTANCE FROM
TILE-SURF BOND LINE

11 INCH
30 INCH
X TO CENTER



X [INCHES]

c. Tile 48 M = 1.8 $\delta_F = 40.04^\circ$

Figure 4 (Continued)

